

Sleeping aggregations of bees in relation to the risk of fire at their roosting sites in a forested, suburban landscape in eastern Australia

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Abstract

Sleeping aggregations of at least 13 bee species (from the families Halictidae, Apidae, Colletidae and Megachilidae) were observed in the forested and fire-prone landscape of the Lane Cove River valley, in suburban, northern Sydney, NSW, Australia, during the years 2002–2012. Bees were often found roosting at sites subjectively assessed as having a lower risk of being burnt. The fire risk of the observed sleeping aggregation sites may have been reduced by bees: 1. roosting in smaller vegetation patches, separated by a clearing from larger, nearby areas of vegetation; or 2. roosting in areas of vegetation recently burnt by fire and therefore at a reduced risk of burning; or 3. roosting at or near the edges of vegetation, giving them a chance to escape into adjacent cleared areas, if a fire arrived when there was enough light for the bees to see and fly away; or 4. roosting at or near the edges of tracks or trails, which might act as fire breaks in the event of lower intensity fires; or 5. using combinations of some of the above four 'strategies'. This study suggests that sleeping aggregations of bees in this fire-prone area generally appeared to have a tendency to occupy roosting sites that were at a lower risk of being burnt, or sites that probably provided more opportunities for the bees to escape an approaching fire. There are a few indications in the published literature that some bee and wasp species in other fire-prone regions of the world may also have a tendency to occupy lower fire risk roosting sites. (*The Victorian Naturalist* 130 (1) 2013, 22–36).

Keywords: bee, fire, sleeping aggregation, communal roost, wasp

Introduction

Communal roosting has been observed in a number of insect groups (reviewed by Yackel Adams 1999), including butterflies (Lepidoptera) (Mallet 1986; Finkbeiner *et al.* 2012), bees and wasps (Hymenoptera) (see references below), dragonflies (Odonata) (Corbet 1999), beetles (Coleoptera) (Pearson and Anderson 1985; Webb 1994), flies (Diptera) (Allee 1927) and owlflies (Neuroptera) (Gomes-Filho 2000). Communal roosting has also been recorded for harvestmen (Opiliones) (Donaldson and Grether 2007).

The males (and occasionally females) of solitary bee species have been observed often gathering in the evening to sleep together at night, in both Australia and worldwide (Rau and Rau 1916; Rayment 1935; Linsley 1958; Evans and Linsley 1960; Linsley 1962; Michener 1974; Houston 1984; O'Toole and Raw 1991; Dollin *et al.* 2000; Alves-dos-Santos *et al.* 2009; and see images posted on the internet, e.g. www.austrianativebees.com). Similar behaviour has also often been observed in male and female wasps (Banks 1902; Bradley 1908; Rau and Rau 1916; Rau 1938; Evans and Linsley 1960; Linsley 1962; Evans and Gillaspay 1964; Callan 1984;

O'Neill 2001; Evans and O'Neill 2007). The term generally applied to communal roosting in bees and wasps is 'sleeping aggregation'. Male bees can form loose or dense sleeping aggregations, occasionally consisting of several species and ranging from a few bees to hundreds of individuals (Rayment 1935; Michener 1974; O'Toole and Raw 1991). Sometimes female bees may also be found sleeping near the males (Rayment 1935; Linsley 1962; Michener 1974). Typically, however, the females of most solitary bee species spend the night in nests, whereas the males of various species sleep together in communal roosts (Linsley 1958; Evans and Linsley 1960).

Bee sleeping aggregations tend to form towards the end of the day and, weather permitting, disband again the next morning (Evans and Linsley 1960; Linsley 1962; Alcock 1998). Roosting sites may be used by groups of male bees on successive nights for prolonged periods and the same sites are sometimes used by following generations of male bees in subsequent years (Evans and Linsley 1960; Linsley 1962; Alcock 1998; Wcislo 2003).

The most common type of sleeping aggregation probably involves male bees attaching themselves, either by the jaws and/or with their legs, to the stems or leaves of living or dead plants. Less commonly, males of various bee species may form sleeping aggregations in flowers, in communal burrows, under bark, in crevices or cracks, on seed pods and in bird nests (Rayment 1935; Linsley 1958; Cazier and Linsley 1963; Linsley and Cazier 1972; Raw 1976; Maynard 1991; O'Toole and Raw 1991; Azevedo and Faria 2007). In denser aggregations some of the bees may rest on top of each other, without contacting the substrate (Cazier and Linsley 1963). One of the intriguing aspects of these sleeping aggregations is that, whilst some male bees may compete aggressively with each other for mates during the daytime, the same individuals can be capable of peacefully roosting together at night (Raw 1976; O'Toole and Raw 1991).

The reason(s) for the formation of bee and wasp sleeping aggregations have apparently not been well understood (Rau and Rau 1916; Evans and Linsley 1960; Michener 1974; Döllin *et al.* 2000; Wcislo 2003; Alves-dos-Santos *et al.* 2009; Matthews and Matthews 2010). A number of researchers have put forward possible explanations for this phenomenon, often focusing on protection from predators and/or on thermoregulatory benefits (Rayment 1935; Rayment 1956; Evans and Linsley 1960; Linsley and Cazier 1972; Freeman and Johnston 1978; Callan 1984; Alcock 1998; Silva *et al.* 2011). A social function was suggested as a possible reason for sleeping aggregations in *Steniolia obliqua* wasps (Crabronidae) by Evans and Gillaspay (1964). However, it would appear that none of these explanations has been definitely proven (see Yackel Adams 1999, for a discussion of the possible function(s) and adaptive significance of communal roosting in bees and other insects). Similar and additional explanations have been suggested to account for aggregative behaviour in a wide range of animal species (Allee 1927; Ward and Zahavi 1973; Stephens and Sutherland 1999; Stephens *et al.* 1999; Marzluff *et al.* 1996; Bell *et al.* 2007; Grether and Donaldson 2007; Finkbeiner *et al.* 2012).

Matthews and Matthews (2010) considered that sleeping aggregations of bees are not in-

ternally organised and do not involve co-operative behaviour. However, it is possible that such aggregations might be an early step along the path towards the more co-operative behaviour of complex insect societies, as indicated by Rau and Rau (1916) and Rayment (1956). Aggregation pheromones may be involved in the formation of sleeping aggregations in bees and wasps (see Freeman and Johnston 1978; Alcock 1998; Wcislo 2003; Silva *et al.* 2011). Aggregation pheromones have been reported for a diverse range of non-social arthropods, including a few species of Hymenoptera (Wertheim *et al.* 2005).

Fire is important in shaping many terrestrial ecosystems in Australia and worldwide. Some researchers have studied the effects of fire on bee communities (Potts *et al.* 2003; Moretti *et al.* 2009; Grundel *et al.* 2010) and on individual bee species (Stow *et al.* 2007; Maynard and Rao 2010; Cane and Neff 2011).

The aim of this current study is to explore whether there might be a relationship between the roosting sites of bee sleeping aggregations and the risk of fire at those sites in the bushland of northern Sydney.

Study area

Observations for this study were made in the Lane Cove River valley of suburban northern Sydney, NSW, Australia. Surviving natural vegetation in the study area includes open-forest, tall forest, woodland, heathland, rainforest, riparian shrubland, mangrove forest, rushland and saltmarsh (Clarke and Benson 1987; Benson and Howell 1990; Benson and Howell 1994; Martyn 2010). Much of the surviving bushland in the Lane Cove River area is sclerophyllous, is situated on sandstone and has been broadly described by Keith (2004) as the Sydney Coastal Dry Sclerophyll Forests. This bushland has undergone varying degrees of fragmentation and the majority of the Lane Cove River catchment's natural vegetation has been cleared, for timber, agriculture and subsequently for suburban development, which has intensified in recent years. A more or less contiguous band of bushland survives along the course of the river and some of its tributaries. The largest areas of native vegetation occur in the upper reaches. Introduced weed species frequently

dominate the study area's watercourses and also disturbed places, such as bushland edges. Even so, the study area still has a high diversity of native plant species.

Much of the vegetation in this study area could be described as 'fire-prone', in the sense that it is likely to be burnt quite frequently. The sclerophyllous vegetation is the most 'fire-prone', but areas containing rainforest species, mangroves, rushland and saltmarsh may also be burnt under extreme weather conditions. However, some patches of sclerophyllous bushland in the study area may escape being burnt for relatively long periods of time. Arson and planned fires set by bushland managers (for the purposes of hazard reduction and ecological management) are probably the two most common causes of bushfire in the Lane Cove River area in recent times. Occasionally, large wildfires have swept through the valley, e.g. in January 1994. Such fires can reach high intensities, depending on fuel levels in the bushland and weather conditions at the time of burning. Smaller bushfires occur fairly frequently in the Lane Cove River valley.

Methods

In the years 2002-2012 some bushland areas in the Lane Cove River valley were searched for sleeping aggregations of bees. Generally, searches were conducted in the late afternoon. The first aggregation was found by chance in 2002, when I was not looking for roosting bees. The pattern of searching tended to be biased towards looking along walking tracks, service trails and the edges of bushland because such places are easier to search. I attempted to counteract this bias by also searching bushland away from tracks and trails. Narrow tracks surrounded by thick, unburnt bushland were also searched and these were considered to be a very high fire risk situation for any bees that might have been found roosting along them. Several aggregations were found in a suburban garden in the vicinity of the Lane Cove River, located well away from the nearest bushland. A few bees (from eight species) were taken from a handful of the observed aggregations and sent for identification to Michael Batley, who also identified some bees from photographs. However, the bee species in the majority of the sleeping ag-

gregations were tentatively identified (without capturing the bees) by consulting Dollin *et al.* (2000) and by referring to the identifications, provided by Michael Batley, of similar looking bees. Some bees were not identified and these are grouped together as 'unidentified species' in Table 1. The number of bees in the smaller aggregations was counted, whilst bee numbers were estimated for larger aggregations.

The fire risk of each roosting site was subjectively assessed, taking into account characteristics such as the proximity and density of adjacent vegetation, the amount of leaf litter and other fuels present and the length of time since the last fire. Other factors that could potentially have modified the risk of fire to the bees were also noted, including whether the sleeping aggregation was situated on the edge of the bushland area, or next to a service trail or walking track. Roosting sites were given a subjective fire risk rating, ranging from very low to very high. Even when rain had recently fallen at a roosting site, the fire risk was assessed on the basis of what the risk would have been at the site under dry conditions. It was considered that, even in wetter periods, bushland could dry out quite quickly in the event of a run of successive hot, dry days without rainfall.

Results

Observations of bee sleeping aggregations made during this study are summarised in Table 1. At least 13 bee species (from the families Halictidae, Apidae, Colletidae and Megachilidae) were observed forming communal roosts. In some years more effort was put into searching for sleeping aggregations than in other years and this may largely account for variations in the numbers of aggregations found in different years. Generally, the number of bees found in roosts tended to peak in late spring to early or mid-summer. Sometimes sleeping aggregations persisted into late summer or autumn, but the numbers of bees aggregating at those times of the year were generally smaller. Of the small number of bees taken for identification, all were found to be males (M. Batley pers. comms.). Species from all of the bee families occurring in the study area were observed forming sleeping aggregations. Communal roosts of bees in the family Halictidae were the most frequently

Table 1. Some sleeping aggregations of bees observed in northern Sydney bushland, in relation to the subjectively assessed fire risk of their roosting sites. (Some roosting sites were in weed patches separate from or adjacent to natural vegetation). **Aggregation size** (maximum number of bees seen during the period of observation for each aggregation): v. **small** = 2–6 bees, **small** = 7–25 bees, **medium** = 26–50 bees, **large** = 51–200 bees, v. **large** = more than 200 bees (numbers were estimated for the larger aggregations), **loose** = a loose aggregation; **Roosting substrate**: (D) = bees roosted on a dead plant's skeleton, (L) = bees roosted on a living plant, (dt) = bees roosted on dead twig(s) of a living plant; **Fire risk (modifying factors)**: E = roosted on edge of vegetation, te = roosted on edge of a track, RB = roosting site recently burnt; 'x'M = site burnt 'x' months prior to observation, B = roosting site burnt, sfb = roosted separate from bushland; 'x'M = roosted approx. 'x' metres from edge of bushland; garden = roosted in a garden (away from bushland); ? = uncertainty of species identification; * = an exotic or introduced plant species; (s.g.) = a member of the *Lipotriches flavoviridis* species group (probably *L. excallens*).

Family / Species	Date(s) of aggregation (month & year)	Aggregation size	Roosting substrate	Fire risk of roost site (subjectively assessed); risk modifying factors
Colletidae				
<i>Euryglossa subsericea</i>	Oct 2009	medium	<i>Melaleuca</i> sp. (L)	very low (garden)
? <i>Euryglossa subsericea</i>	Nov 2011	large	<i>Melaleuca</i> sp. (L-dt) (same site as Oct 09)	very low (garden)
? <i>Leioproctus thornleighensis</i>	Dec 2007	medium	<i>Kunzea ambigua</i> (L)	low to medium; te
<i>Leioproctus thornleighensis</i>	Jan 2011	medium	<i>Kunzea ambigua</i> (L) and <i>Grevillea sericea</i> (L)	high; E
Megachilidae				
<i>Megachile ferox</i>	Nov–Dec 2002	small	<i>Pimelea limifolia</i> (D)	low–RB7M; E
<i>Megachile leucopyga</i>	Nov 2010	small	*grass leaf (D) - weedy area	very low - sfb (c. 30m)
<i>Megachile</i> sp.	Oct–Nov 2007	very small	*weed (D)	low–sfb (c. 3m)
Apidae				
<i>Amegilla</i> ? <i>bombiformis</i>	Feb–Mar 2004	very small	<i>Kunzea ambigua</i> (D)	low - RB14M; te
<i>Amegilla</i> ? <i>bombiformis</i>	Feb–Mar 2005	very small	*weed (D)	low - sfb (c. 5 m)
<i>Amegilla zonata</i> (species group)	Mar 2003	small	<i>juncus</i> sp. (L)	low - sfb (c. 5 m)
<i>Amegilla</i> sp. (banded bee)	Feb, Mar 2005	one bee	*weed (D) (with A. ? <i>bombiformis</i>)	low–sfb (c. 5 m)
<i>Amegilla</i> sp. (banded bee)	Jan 2006	very small	<i>Schoenus melanostachyis</i> (L)	medium; te
<i>Amegilla</i> sp. (banded bee)	Jan 2007	very small	*weed (D)	low–sfb (c. 3–5 m)
<i>Amegilla</i> sp. (banded bee)	Jan 2008	very small	<i>Rumex</i> sp. (L)	low to medium; E
<i>Amegilla</i> sp. (banded bee)	Jan–Feb 2012	small	grass and <i>Euclyptus</i> sp. (L)	low - sfb (c. 3m)
<i>Thyreus</i> ? <i>nitidulus</i>	Dec 05, Jan 06	very small (loose)	* <i>Brassica</i> sp. (D)	low to medium; E
<i>Thyreus</i> ? <i>nitidulus</i>	Nov 2005	one bee	plant stem (D)	low to medium; E
<i>Thyreus</i> ? <i>nitidulus</i>	Jan 2006	one bee	<i>Allocasuarina littoralis</i> (D)	medium; E (above cleared area)
<i>Thyreus</i> ? <i>nitidulus</i>	Jan–Feb 2007	very small (loose)	* <i>Brassica</i> sp. (D)	medium; E
Halictidae				
? <i>Homalictus punctatus</i>	Jan–Feb 2005	med–large	<i>Exocarpos cupressiformis</i> (L)	medium to high; te
? <i>Homalictus punctatus</i>	Dec 2005	very small	as above (same site)	as above
? <i>Homalictus punctatus</i>	Nov 2006	small	as above (same site)	as above

Table 1 (cont.)

Family / Species	Date(s) of aggregation (month & year)	Aggregation size	Roosting substrate	Fire risk of roost site (subjectively assessed); risk modifying factors
? <i>Homalictus punctatus</i>	Jan 2007	small	as above (same site)	as above
<i>Homalictus punctatus</i>	Oct–Nov 2007	small	as above (same site)	as above
<i>Homalictus punctatus</i>	Dec 2010	large	<i>Allocasuarina littoralis</i> (L)	high; E
? <i>Homalictus punctatus</i>	Feb 2012	very small	<i>Leptospermum trinervium</i> (L-dt)	low–B; c.1.2–24M; te
<i>Lasioglossum</i> subgenus <i>Australictus</i>				
? <i>Lasioglossum peraustrale</i>	Dec 2006	small	<i>Casuarina glauca</i> (L)	low
? <i>Lasioglossum peraustrale</i>	Dec 2006	medium	<i>Casuarina glauca</i> (L)	very low – sfb
<i>Lasioglossum peraustrale</i>	Dec 07–Jan 08	medium	<i>Casuarina glauca</i> (L)	low
? <i>Lasioglossum peraustrale</i>	Dec 10–Jan 11	small	<i>Acacia ?decurrens</i> (L)	medium; E
? <i>Lasioglossum peraustrale</i>	Dec 2011	very small	<i>Casuarina glauca</i> (L)	low
? <i>Lasioglossum peraustrale</i>	Dec 11–May 12	large	<i>Melaleuca linariifolia</i> (L)	medium; te
? <i>Lasioglossum peraustrale</i>	Jan–Mar 2012	medium	<i>Acacia meurnsii</i> (L)	high; E (above edge of clearing)
? <i>Lasioglossum peraustrale</i>	Jan–May 2012	small	* <i>Melaleuca armillaris</i> (L-dt) (planted)	very low–sfb (c.5 m)
? <i>Lasioglossum peraustrale</i>	Apr–May 2012	small	<i>Allocasuarina littoralis</i> (L)	low–sfb
<i>Lasioglossum</i> subgenus <i>Chilalictus</i>				
<i>Lasioglossum convexum</i>	Feb–Mar 2003	small	<i>Allocasuarina littoralis</i> (D)	very low – RB10M; te
? <i>Lasioglossum instabilis</i>	Jan 2005	small	<i>Aristida vagans</i>	medium; te
<i>Lasioglossum instabilis</i>	Jan–May 2005	medium	<i>Themeda australis</i>	medium; near te
? <i>Lasioglossum instabilis</i>	Dec 05–Jan 06	large	<i>Bossiaea obcordata</i> (L) and <i>Themeda australis</i>	medium
? <i>Lasioglossum instabilis</i>	Jan 2006	very small	? <i>Digitaria</i> sp.	medium to high; te
? <i>Lasioglossum instabilis</i>	Jan–Mar 2006	small	<i>Themeda australis</i>	medium; te
? <i>Lasioglossum instabilis</i>	Nov–Dec 2006	medium	<i>Themeda australis</i>	medium; near te
? <i>Lasioglossum instabilis</i>	Dec 06–Jan 07	large	<i>Themeda australis</i>	medium; E
? <i>Lasioglossum instabilis</i>	Dec 06–Jan 07	large	<i>Themeda australis</i>	medium; E
? <i>Lasioglossum instabilis</i>	Dec 06–Jan 07	small	<i>Themeda australis</i>	medium; E
? <i>Lasioglossum instabilis</i>	Dec 06–Jan 07	small	<i>Themeda australis</i>	medium; E
? <i>Lasioglossum instabilis</i>	Dec 06–Jan 07	medium	<i>Dianella revoluta</i> (L-dt)	high; E
? <i>Lasioglossum instabilis</i>	Nov 06–Jan 07	large	<i>Themeda australis</i> (L) and <i>Aristida vagans</i>	medium to high; te
? <i>Lasioglossum instabilis</i>	Nov 2009	large	<i>Themeda australis</i> (L)	high; E
<i>Lipotriches fortior</i>	Jan–Feb 2011	large	*conifer (L-dt) - tree	low–sfb (c.4 m)
<i>Lipotriches australica</i>	Nov–Dec 2002	small	* <i>Chlorophytum comosum</i> (L)	low – RB; E
<i>Lipotriches australica</i>	Feb 2003	very small	<i>Pimelea linifolia</i> (D)	very low – RB10M; E

<i>Lipotriches australica</i>	Dec 2006	large	* <i>Paspalum</i> sp.	low-sfb
<i>Lipotriches australica</i>	Dec 2006	very large	* <i>Cardiospermum</i> sp.	low to medium; E
<i>Lipotriches australica</i>	Dec 06-Jan 07	large	*weeds (D) and * <i>Verbena bonariensis</i> (L)	low-sfb (c.10 m)
<i>Lipotriches australica</i>	Jan 2007	large	wire mesh fence - probably moved from	
<i>Lipotriches australica</i>	Jan 2007	large	* <i>Paspalum</i> - see Dec 2006 (above)	very low
<i>Lipotriches australica</i>	Jan 2007	small	* <i>Plantago lanceolata</i>	medium; near E
<i>Lipotriches australica</i>	Dec 2007	small	* <i>Paspalum</i> sp. (L)	medium; E
<i>Lipotriches australica</i>	Jan-Feb 2011	large	* <i>Verbena bonariensis</i> (L)	low-sfb
<i>Lipotriches australica</i>	Jan-April 2012	very large	* <i>Verbena bonariensis</i> (L) & * <i>Cardiospermum</i> sp.	low to medium; E
<i>Lipotriches australica</i>	Jan-Feb 2012	large	*weed (D)	low to medium; E
<i>Lipotriches australica</i>	Jan 2012	medium	* <i>Verbena bonariensis</i> (L)	low - sfb (c.10m)
<i>Lipotriches australica</i>	Feb 2012	medium	* <i>Bidens pilosa</i> (L)	medium; E
<i>Lipotriches australica</i>	Feb-Mar 2012	medium	* <i>Sida rhombifolia</i> (L) and * <i>Paspalum</i> sp.	medium-high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2002	large	<i>Pimelea linifolia</i> (D)	very low - RB8M; E
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-April 2003	small-med.	<i>Pimelea linifolia</i> (D)	very low - RB9M; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-Mar 2003	small	<i>Pimelea linifolia</i> (D)	very low - RB10M; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-Mar 2003	small	<i>Zieria smithii</i> (D)	very low - RB2M; te
<i>Lipotriches flavoviridis</i> (s.g.)	March 2003	very small	<i>Dilwynia retorta</i> (D)	very low - RB3M; te
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2005	large	? <i>Kunzea ambigua</i> (D)	medium; near E
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2005	medium	* <i>Plantago</i> and grass (D)	medium to high; te - above
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2005	medium	<i>Pimelea linifolia</i> (D)	track
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2005	small	<i>Themeda australis</i>	medium to high; te
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-April 2005	medium	? <i>Kunzea ambigua</i> (D)	low - B26M; te - above
<i>Lipotriches flavoviridis</i> (s.g.)	Mar 2005	very small	<i>Juncus</i> sp. (D)	low; E
<i>Lipotriches flavoviridis</i> (s.g.)	Sep 2005	one bee	<i>Bursaria spinosa</i> (L-dt) (site v. close to Feb 06)	medium; E
<i>Lipotriches flavoviridis</i> (s.g.)	Nov-Dec 2005	large	plant (D) and <i>Themeda</i>	medium; E (very close to
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2006	medium	* <i>Pavonia hastata</i> (L) and <i>Pimelea linifolia</i> (L)	Feb 2006 - see below)
<i>Lipotriches flavoviridis</i> (s.g.)	Nov-Dec 2005	very small	<i>Pimelea linifolia</i> (D)	low; E - above edge of
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2006	small	<i>Themeda australis</i>	cleared area
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2006	small	<i>Themeda australis</i>	medium to high; te - above
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-March 2006	large	<i>Bursaria spinosa</i> (L) and <i>Lepidosperma laterale</i>	track
<i>Lipotriches flavoviridis</i> (s.g.)	Nov-Dec 2006	small	<i>Themeda australis</i>	medium; E
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2007	small	<i>Dianella revoluta</i> (L-dt) (near ? <i>L. instabilis</i>)	medium to high; te
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2007	small	* <i>Bidens pilosa</i> (D)	- above track
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2007	large	* <i>Sida rhombifolia</i> (D) and * <i>Hypochaeris</i> (D)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb 2007	large	* <i>Bidens pilosa</i> (D)	low to medium
<i>Lipotriches flavoviridis</i> (s.g.)	Nov 2007	medium	<i>Dianella revoluta</i> (L)	medium; near E
<i>Lipotriches flavoviridis</i> (s.g.)	Nov 2007	medium	* <i>Sida rhombifolia</i> (L)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Nov-Dec 2007	medium	<i>Acacia ulicifolia</i> (L)	medium
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2007	small	* <i>Plantago lanceolata</i> (L)	medium; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2007	small		low - sfb

Table 1 (cont.)

Family / Species	Date(s) of aggregation (month & year)	Aggregation size	Roosting substrate	Fire risk of roost site (subjectively assessed); risk modifying factors
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2007	small	*weed (D)	low - sfb (c.10 m)
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2007	large	*weed (D) and <i>Senecio</i> (L)	low
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2008	small	plant (D)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2008	large	*weeds (D)	low
<i>Lipotriches flavoviridis</i> (s.g.)	Nov 2009	small	<i>Dianella revoluta</i> (L)	medium to high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 09-Jan10	large	* <i>Sida rhombifolia</i>	low
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2010	medium	* <i>Bidens pilosa</i> (D)	low to medium
<i>Lipotriches flavoviridis</i> (s.g.)	Jan 2011	large	*grass (L)	low to medium
<i>Lipotriches flavoviridis</i> (s.g.)	Mar 2011	small	* <i>Coleonema pulchrum</i> (L) - planted	very low (garden)
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2011	medium	*weed (D) (herb)	very low-sfb (c.4m)
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 11-Jan 12	medium	<i>Viminaria juncea</i> (L-dt)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 11-Jan12	large	* <i>Sida rhombifolia</i> (L-dt)	low to medium
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2011	small	<i>Themeda australis</i>	low
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 11-Mar 12	large	<i>Dianella revoluta</i> (L-dt)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 2011	small	* <i>Coleonema pulchrum</i> (L) - same site as March 2011	very low (garden)
<i>Lipotriches flavoviridis</i> (s.g.)	Dec 11-Feb12	large	* <i>Brassica</i> sp. (D)	medium; near E
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2012	very small	<i>Themeda australis</i>	high; near E
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2012	medium	<i>Themeda australis</i> (planted)	low-native garden-sfb
<i>Lipotriches flavoviridis</i> (s.g.)	Jan-Feb 2012	medium	<i>Ozothamnus diosmifolius</i> (L-dt)	low to medium; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-Mar 2012	small	<i>Lepidosperma laterale</i> (L)	high; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb 2012	very small	<i>Microlaena stipoides</i>	low-RB; E
<i>Lipotriches flavoviridis</i> (s.g.)	Feb-April 2012	small	<i>Cymbopogon refractus</i> (L)	high; E
Unidentified Species				
small, dark bee	Oct-Nov 2009	small	<i>Ozothamnus diosmifolius</i> (L)	high; E-above edge of cleared area
dark bee	Nov 2009	very small (loose)	<i>Gahnia</i> sp. (L)	medium to high; te
medium-sized, dark bee	March 2010	very small	* <i>Coreopsis lanceolata</i> (L) (flower)	low to medium
small, dark bee	Dec 2010	small	<i>Austrostipa</i> sp.	medium to high
small, dark bee	Dec 11-Jan 12	small	<i>Allocasuarina littoralis</i> (L)	low to medium; E
small, dark bee	Dec 11-Jan 12	medium	<i>Austrostipa</i> sp.	medium to high
small, dark bee	Jan-May 2012	large	<i>Dillwynia retorta</i> (L-dt)	medium to high
small, dark bee	Jan 2012	one bee	* <i>Hypochoeris</i> sp. (L) (flower) (roosting near <i>L. flavoviridis</i> s.g.)	low to medium; E
small, dark bee	Feb 2012	large	<i>Dianella caerulea</i> (L-dt)	high
small, dark bee	Feb-April 2012	large	<i>Allocasuarina littoralis</i> (L) - possibly planted	low-sfb
dark-coloured bee	Feb 2012	very small	* <i>Hypochoeris</i> sp.	medium to high; E

observed and, within this family, bees of the *Lipotriches flavoviridis* species group (probably '*L. excellens*') were most often seen aggregating to roost together at night.

Bees were found roosting mostly on vegetation, including living grasses, sedges, herbs, shrubs and trees. Also, some bees roosted on the skeletons of dead plants or on dead twigs attached to living plants. One aggregation of *Lipotriches australica* spent some time roosting on a wire mesh fence. Bees roosted mostly at a height of less than two metres and often less than one metre above ground level. A few mixed aggregations, comprising several species, were observed, but most of the sleeping aggregations consisted of a single species. The majority of the observed sleeping aggregations were compact or dense, that is to say that most of the bees in each aggregation slept in close proximity to each other, often resting in contact with one or more of the other bees at the roost. Some of the sleeping aggregations apparently lasted for a longer time than others. However, some aggregations were observed for only one or a few days, so the actual duration of those aggregations was not determined. Also, the initial formation of an aggregation was rarely observed, so most of the aggregations probably existed for some time before they were first detected.

Bees often roosted in places that were apparently at a lower risk of being burnt than many other potential roosting sites in the surrounding landscape. Some of the bees formed sleeping aggregations in smaller patches of vegetation that were separated by a clearing from larger, nearby areas of denser bushland. For example, in December 2006 a sleeping aggregation of *Lipotriches australica* (Halictidae) (see front cover) was found on a relatively small patch of herbaceous weeds (Fig. 1) that was separated from the nearby larger area of bushland by a mowed, grassy clearing. The nearby open-forest had not been burnt for many years and no bees could be found roosting in this relatively high fire risk bushland. Another example occurred in December 2007 when a small aggregation of *Lipotriches flavoviridis* (species group) bees (Fig. 2) roosted on *Plantago lanceolata*, near the base of a remnant eucalypt (Fig. 3), separated from the nearby, dense bushland by a mowed

grassy area. Other similar examples included the aggregation of *Lipotriches fortior* found roosting on an exotic conifer in January/February 2011, separated from bushland by a cleared area and also several aggregations of *?Lasioglossum peraustrale* (Halictidae) that roosted on trees separate from nearby bushland.

Bees sometimes roosted in areas of recently burnt vegetation located close to areas of unburnt bushland. For example, in November / December 2002 an aggregation of *Megachile ferox* (Megachilidae) bees roosted on the edge of an area of open-forest that had been burnt by a small fire approximately seven months earlier. The fire risk of this roosting site was relatively low because sufficient time had not elapsed since the recent fire for fuel loads to build up again. While *M. ferox* were roosting at this site, a wildfire burnt a larger area of the nearby adjoining forest, much of which had not been burnt for a long time. This fire burnt to within several hundred metres of where the bees were roosting. *Megachile ferox* continued to roost at the same site for several weeks after the occurrence of the nearby wildfire.

When bees roosted in places of higher fire risk they were often found at or near the edges of the bushland. This positioning may have given them the chance to escape into the adjacent cleared areas in the event of a fire, provided that such a bushfire occurred when there was sufficient light available and the bees were alert enough to fly away. Bees sometimes roosted on or near the edge of walking tracks. Some of these tracks could have acted as fire breaks in the event of lower intensity fires.

The apparent tendency to roost in lower fire risk locations may have varied somewhat between species. For example, some of the smaller bee species apparently tended to roost more frequently in places with a relatively higher risk of being burnt. However, more observations would be required to confirm whether this is generally the case. No bees were observed forming sleeping aggregations at sites considered to be at a very high risk of being burnt, even though narrow tracks that had thick bushland growing on either side of them were searched and some areas within denser vegetation were also searched.



Fig. 1. *Lipotriches australica* roosting site, December 2006 (bees are on band of weeds in the right foreground).



Fig. 2. *Lipotriches flavoviridis* (s.g.) sleeping aggregation, December 2007.

Discussion

These observations of sleeping aggregations over a period of a decade indicate that, in this fire-prone study area in south-eastern Australia, bees generally appear to occupy roosting sites with a lower risk of burning. Many other researchers have observed sleeping aggregations of bees and wasps. Some of these studies were conducted in fire-prone landscapes and provide a few indications that bees and wasps in other parts of the world may also tend to occupy lower fire risk roosting sites in fire-prone regions.

Bees and wasps roosting in sites possibly protected from fire

Bradley (1908) found a large concentration of sleeping aggregations, mostly of wasps, but including three bee species, in California, USA. His observations were made during summer in the San Joaquin Valley, when the vegetation had been parched by more than a month of hot, dry conditions. The large numbers of wasps (and a few bees) were aggregated at intervals along a road for 'perhaps a mile or more'. The roosting



Fig. 3. *Lipotriches flavoviridis* (s.g.) roosting site, December 2007 (bees are in bottom right hand part of photo).

groups of wasps and bees were scattered along a narrow strip of dried vegetation between the road and a recently harvested grain field. On the other side of the road from the sleeping aggregations of wasps and bees, the vegetation had been recently burnt by 'extensive prairie fires'. Bradley searched the sagebrush and foxtail grass on the plains 'twelve miles distant', but was unable to find any other sleeping aggregations of wasps. This suggests that these wasps and bees may have selectively occupied a roosting site that was at a lower risk of burning, compared with alternative sites on the plains.

In this present study sleeping aggregations of bees were sometimes found on smaller vegetation patches, separated by a clearing from larger, nearby areas of vegetation. This behaviour may have protected the bees from the greater risk of fire involved in roosting in the larger areas of vegetation, just as the wasps (and bees) that Bradley observed in the San Joaquin Valley may have received some protection by roosting in a narrow roadside strip of vegetation. Some of the bees observed in my study roosted at or near the edges of tracks or trails. This may possibly have given them some protection from fire, as some of these tracks could potentially have acted as fire breaks in the event of lower intensity fires. However, this would probably not apply to very narrow tracks surrounded by thick, fire-prone vegetation. Price and Bradstock (2010) found evidence to indicate that roads may stop some fires in the dry sclerophyll forests of the Sydney region.

Evans and Linsley (1960) and Linsley (1962) studied a diverse array of bee and wasp species

gathered together in a concentration of sleeping aggregations in the Chiricahua Mountains, in Arizona, USA. The site of these aggregations was a meadow, approximately 30 m × 90 m (ca. 100 × 300 feet), situated opposite a building, across an access road and car parking area, at a research station. The brief site description provided by the authors suggests that the meadow may have been somewhat protected from fire, at least on one side. This meadow roosting site occupied by these bees and wasps may have served as a refuge from fires, when compared with the woodlands surrounding the research station, which may have been more likely to be burnt than the meadow. The vegetation of the Chiricahua Mountains is prone to fires and there was recently a major wildfire in the area.

Bees roosting in recently burnt areas

Rau and Rau (1916) found two sleeping aggregations of male *Svastra obliqua* (as *Melissodes obliqua*) (Apidae) bees roosting on scorched leaves in recently burnt areas in open fields in Missouri, USA, but they were unable to find bees of this species roosting in nearby unburnt vegetation. Frankie *et al.* (1980) studied the bee *Centris adani* (Apidae) at a site, consisting of farmland interspersed with patches of regrowing dry forest, in Costa Rica. Their study site included areas of unburnt tall grass and 'brush', but the only sleeping aggregation of male bees that they found was located in a recently burnt area. In this present study, an aggregation of *Megachile ferox* (Megachilidae), some aggregations of *Lipotriches flavoviridis* (species group) (Halictidae) and one aggregation of *Amegilla*

?*bombiformis* (Apidae) bees were found roosting in recently burnt areas.

Before European settlement there were large areas of fire-prone contiguous vegetation in the Sydney district and roosting in recently burnt areas may have been an important way for bees to avoid the hazard of fire. Also, bees may have used vegetation associated with larger rock outcrops as roosting sites, because such situations may have offered some protection from fire. Even though much of the bushland closer to Sydney is now fragmented, it seems likely that recently burnt areas may still offer roosting bees a refuge from the risk of fire in those suburbs of the city that have retained some remnant natural vegetation (such as in the Lane Cove River valley).

Schowalter (2000) indicated that some insects with longer (2–5 year) generation times may avoid places where litter has accumulated in fire-prone ecosystems. Miller and Wagner (1984) found that pupae of the Pandora Moth *Coloradia pandora pandora* (Saturniidae), in a pine forest in Arizona, tended to occur in greater numbers where fuel loads were lighter on the ground and the canopy was more open. They speculated that this tendency may have reduced the risk of the pupae being killed by fire. Frost (1984) stated that some bird species apparently prefer to nest on recently burnt ground and suggested that these birds might be able to detect predators more easily and that predators might be less plentiful in recently burnt areas. The eggs, chicks and nesting adults of these birds would also be less exposed to the risk of their being killed by fire, as recently burnt areas would be less likely to support fires than unburnt areas. Frost noted that some of these bird species have dark coloured eggs and chicks and suggested that these might be ‘adaptations’ to nesting on blackened ground.

Rau and Rau (1916) observed that the brown bodies of the bee *Svastra obliqua* (Apidae) blended very well with the ‘dingy’ burned leaves of the scorched plants on which some of these bees roosted in the two recently burnt areas mentioned above. In this current study it was noted that the generally brownish colouration of *Lipotriches flavoviridis* (species group) (Halictidae) bees blended effectively with the brownish stems of the scorched *Pimelea lini-*

folia and *Zieria smithii* skeletons that some of these bees roosted upon in recently burnt bushland in 2003. This ‘camouflage’ was particularly effective at lower light levels and when the bees were motionless (and in smaller numbers). This bee species also sometimes roosts on the brownish skeletons of dead plants in areas that have not been recently burnt, as well as on the brownish and green portions of some living plants, in the Lane Cove River valley.

Bees and wasps roosting at the edges of vegetation

Researchers have reported finding bees and wasps roosting at or near the edges of vegetation. For example, Rau and Rau (1916) noted that a thick ‘mass’ of weeds bordering a large open area seemed to be a favoured roosting site for the wasp *Myzinum* sp. (as *Elis 5-cincta*) (Tiphidae) in the USA. Also, Rau (1938) observed sleeping aggregations of the wasp *Prionyx atratus* (as *Priononyx atratum*) (Sphecidae) on weeds at the edge of a harvested wheat field and the wasp *Ammophila nigricans* (Sphecidae) roosting on low plants between a garden and ‘the woods’, in Missouri, USA. Mathewson and Daly (1955) found the bee *Melissodes denticulata* (as *M. perplexa*) (Apidae) aggregating to sleep on *Verbena stricta* in a ‘weedy clearing’ in Kansas, USA. More recently, Hausl-Hofstätter (2008) found a small number of individuals of 8 bee species and 3 wasp species, over a number of years, roosting in a forest clearing, next to a roadside in Croatia. Such observations are similar to those made in this present study, of bees forming sleeping aggregations at or near the edges of vegetation in the Lane Cove River valley. In this study area the remaining fragments of native vegetation have long perimeters, and potential roosting sites at the edges of vegetation are abundant. Observations during the course of this study of apparently suitable roosting sites within unburnt vegetation, away from the edges, indicated that they were mostly unused by bees.

There could be a number of reasons why bees and wasps might favour the edges of vegetation for their roosting sites. For example, they may prefer to roost in more open areas because such places could be more likely to be exposed to sunshine, enabling the insects to use the sun’s

heat to warm themselves before taking off in the morning and/or to keep them warm whilst settling in the afternoon. The potential significance of such thermoregulatory benefits could be illustrated by the observation that sleeping in dark flowers evidently enables some bee species to warm up more quickly in the morning (Dafni *et al.* 1981; Sapir *et al.* 2005; Sapir *et al.* 2006). Kaiser (1995) observed that several roosting solitary bee species became active only after they were exposed to direct sunlight. Another possible benefit of roosting at or near the edge of vegetation is that bees and wasps might be able to flee into the adjacent cleared area, if a fire happened when there was enough light for them to see and fly away. On very warm, sunny days, some bees observed in this study took a long time to settle down at their roosting sites, in the late afternoon or evening, before ceasing activity at or before sunset. On such days, there could be quite a long time when the settling bees would be alert enough to respond to any fire in the vicinity of their roost.

Oldroyd and Wongsiri (2006) noted that the location of drone congregation areas of Asian honey bees is apparently governed by particular physiographic features of the landscape that attract the males. Roosting solitary bee species may also follow simple rules to decide where to roost. For example, some bees and wasps may prefer more open roosting sites. Such a preference may have originated from a possible thermoregulatory benefit provided by roosting in locations more exposed to sunshine, as discussed above. The possible added benefit of a lowered risk of fire may have, in turn, reinforced the initial preference for roosting in more open areas.

The potential reaction of roosting bees to an approaching fire

It is not clear exactly how roosting bees would react to an approaching fire. Visscher *et al.* (1995) quoted reports that worker Honey Bees *Apis mellifera* (Apidae) respond to smoke by engorging themselves with honey drawn from the comb and that smoke reduces the number of guard bees at the hive entrance. They found that applying smoke to isolated *A. mellifera* antennae reduced the response of these antennae to honey bee alarm pheromones. Oldroyd and

Wongsiri (2006) noted that people in south-east Asia, who climb trees for wild bee honey at night, will strike the tree branch near the nest with a torch of bundled burning leaves and that some disoriented bees from the nest will follow the falling sparks, as they cascade downwards. They also considered that hunters using smoke to drive the wild Asian honeybee *Apis dorsata* away from nests during the daytime, before harvesting honey (rather than burning them off at night) are likely to greatly increase the chances of the bee colonies surviving. Frost (1984) noted that ticks may respond to smoke by dropping to the ground to seek shelter and that some grasshoppers are apparently capable of fleeing some fires. Schütz *et al.* (1999) indicated that the Colorado Potato Beetle *Leptinotarsa decemlineata* (Chrysomelidae) responds to high concentrations of fire-generated volatile compounds by exhibiting 'escape behaviour'. If bees can detect smoke from fires, then roosting bees might attempt to fly away from an approaching fire, if it occurred when there was sufficient light for the bees to see. If this is the case, then bees (and wasps) roosting next to a cleared area would probably have a better chance of surviving an intense, fast moving, daytime fire than if they had roosted at a site surrounded by thick vegetation.

Further ways roosting bees and wasps may reduce fire risk

Rau and Rau (1916) observed *Chalybion californicum* (as *C. caeruleum*) (Sphecidae) wasps aggregating under a rock overhang and Rau (1938) found the same species forming sleeping aggregations in an abandoned house, in the USA. Evans *et al.* (1986) noted that males and females of the sand wasp *Bembecinus quinquespinosus* (Crabronidae) slept in clusters under rocks in Colorado, USA. They suggested that the rocks may have protected the wasps from cooler night-time temperatures (and the wind) and helped the wasps to warm up in the morning. It is possible that sleeping under rocks may also provide some wasp species with a degree of protection from fire that they would not receive while roosting on vegetation. In this case, thermoregulation could be the primary benefit and protection from fire might be a secondary benefit of roosting under rocks.

Evans and O'Neill (2007) found that males of the sand wasp *Bembix cursitans* (Crabronidae) constructed unusually deep sleeping burrows at a site in coastal Western Australia. Such burrows could provide the males of this wasp species with protection from fire, at night.

Cane and Neff (2011) indicated that ground-nesting bees may tend to prefer bare patches of ground or soil banks for their nest sites and that this could provide some protection from the heating effects of wildfires, due to the lower levels of fuel at such sites. Other insect species may find more unusual refuges from fire in the landscape. For example, Brennan *et al.* (2011) observed that some insects and other invertebrates survived in experimentally burnt grass trees *Xanthorrhoea preissii* (Xanthorrhoeaceae) in Western Australia.

In fire-prone vegetation, such as much of Sydney's bushland, fire probably poses a significant risk to bee populations. During the daytime, bees might be able to evade fires, depending upon their ability to detect cues such as smoke early enough for them to fly away from the path of an approaching fire. The faster and more intense fires probably pose a greater risk to bees and other insects. The females of some solitary bee species probably receive protection from fires at night because they make their nests by burrowing deeply enough into the ground to avoid over-heating in the event of a fire (Potts *et al.* 2003; Cane and Neff 2011). However, the females and young of some other solitary bee species are probably at a greater risk of being killed by fires because their nesting locations (e.g. inside thin plant stems) are not adequately protected from high intensity fire (Potts *et al.* 2003; Maynard and Rao 2010; Cane and Neff 2011). The males of most bee species in the Sydney region probably sleep on vegetation, in the open, at night. There has probably been selection pressure on roosting bees in the Sydney region, over many centuries, favouring the survival of bees that tend to occupy roosting sites that are at a lower risk of being burnt, or sites affording more opportunity for the roosting bees to flee an approaching fire. This may also apply to bees and wasps in fire-prone environments in other parts of the world.

Further research possibilities

These observations over a ten year period indicated that roosting bees in the study area generally tended to occupy sites at the safer end of the fire risk spectrum. The bee roosting sites appeared not to be randomly distributed throughout the landscape and fire risk reduction appeared to be a likely factor in the location of bee roosting sites in this fire-prone landscape. However, it may be difficult to separate this effect from the possible thermoregulatory benefits gained by bees roosting in more open areas and on the edges of vegetation. Additional field work, possibly supplemented by experimental studies, could help to determine the relative influence of these factors on bee roosting site selection. Another avenue of research could be the response of roosting solitary bee species to approaching fire and the effects of smoke on bee sleeping aggregations.

Concluding remarks

This study indicates that solitary bee species observed forming sleeping aggregations in the fire-prone Lane Cove River valley, in south-eastern Australia, appeared to have a general tendency to roost in sites that were at a lower risk of being burnt, or sites likely to offer a greater chance for the bees to escape a threatening fire. Some bee and wasp species in other fire-prone regions of the world may also show a tendency to occupy lower fire risk roosting sites. The possibility that some roosting bees and wasps occupy sites at a lower risk of burning in fire-prone ecosystems is an idea providing opportunities for further research in both Australia and overseas. More field and experimental work could be required to unequivocally determine whether this idea is valid. There are also unanswered questions surrounding the wider phenomenon of the formation of sleeping aggregations in bees and wasps. The function of such sleeping aggregations is apparently not well understood. It is not clear whether there is one function or whether there are multiple reasons for this behaviour.

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